Prediction of Roadway Surface Conditions Using On-Board Vehicle Sensors

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Presentation Outline

- Introduction (why)
- Vehicle-based safety systems
- Connected Vehicle integration
- Observations on instrumented vehicles
- Friction prediction concept
- Experimental verification
- Challenges, potential pitfalls
- Potential benefits

Introduction

- 24 % of all vehicle crashes in the U.S. occur in adverse weather conditions
  - 7,400 deaths and 675,000 injuries on average per year (years 1995 – 2005)
  - Financial cost of $55 billion (year 2000)
- Slick pavement:
  - Primary cause of 35 % and
  - Contributing cause of 63 % of adverse weather crashes
- About 25% of adverse weather crashes occur on pavement impacted by snow or ice
- Road maintaining agencies spend more than $2.3 billion annually on snow and ice control operations

Vehicle On-Board Safety Systems

- Anti-lock braking systems (ABS)
  - Modulation of brake torque applied at each wheel to minimize slippage
- Electronic Stability Control (ESC) systems
  - Control of applied brake torque and actual throttle to stabilize vehicle, primarily to prevent rollover
- Traction Control Systems (TCS)
  - Modulation of brake torque at individual wheels to transfer applied engine torque to non-slipping wheels

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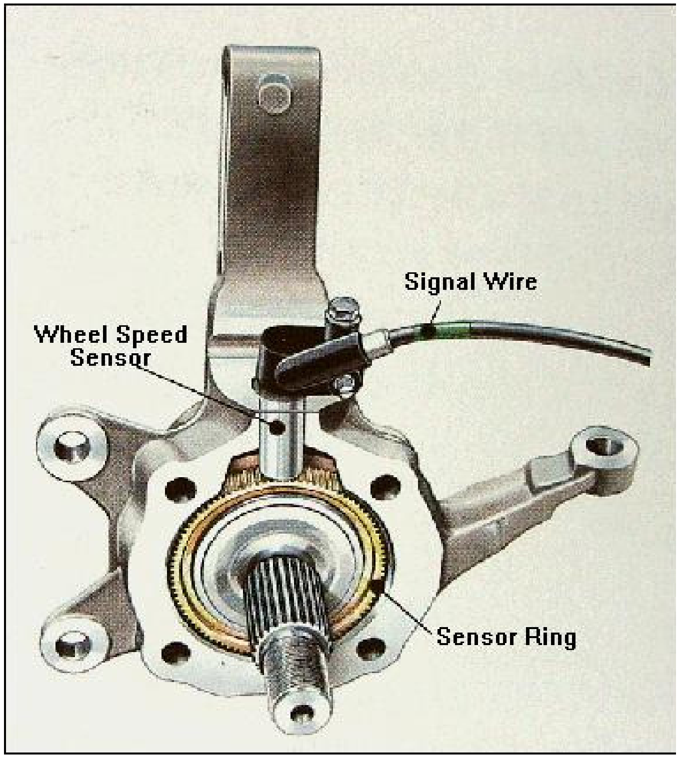
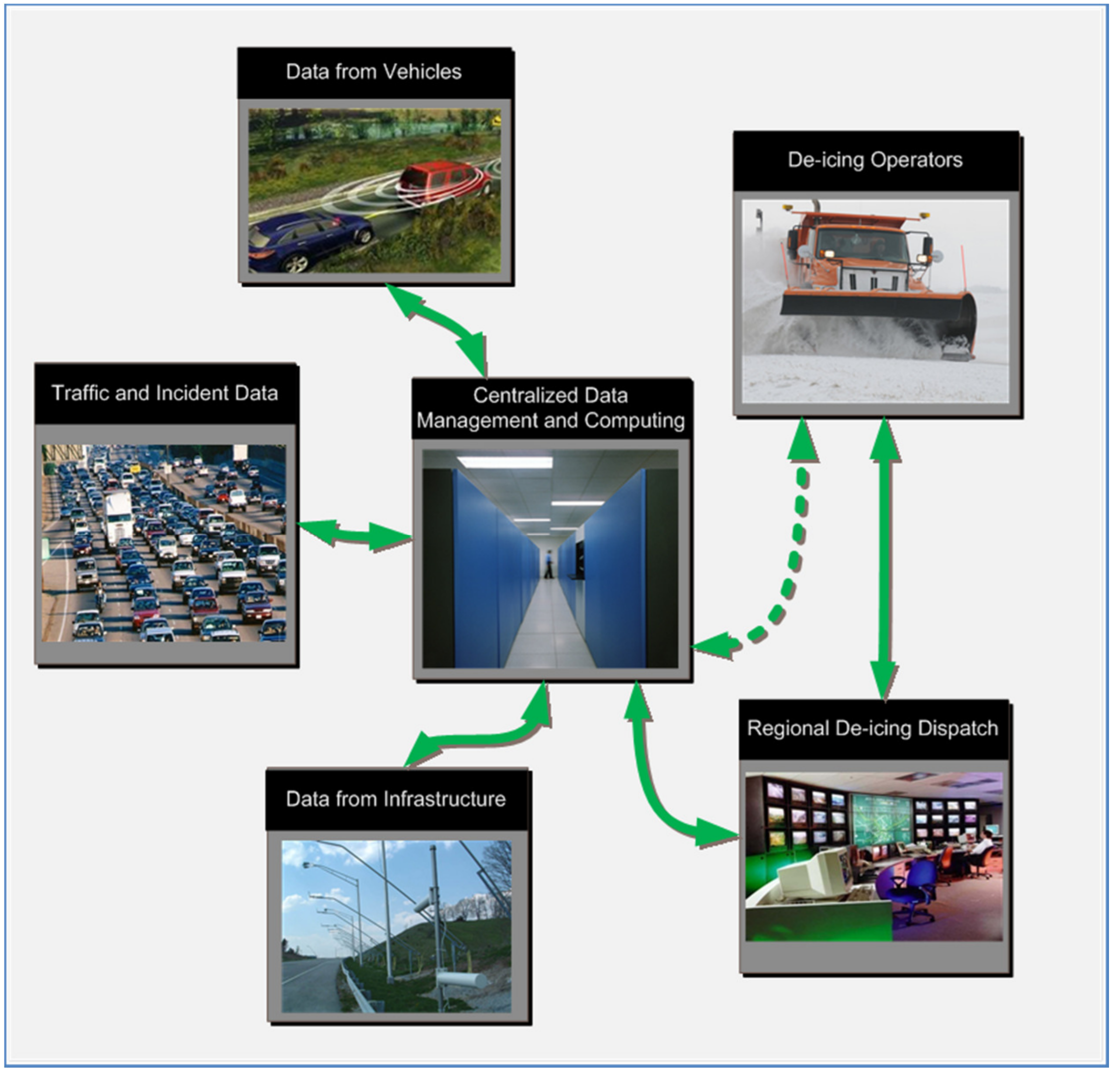
ABS, ESC, TCS Operation

- Depend upon relatively large but short duration tire slip events (macro-slip)
- Theses systems require relatively accurate and timely wheel rotation measurement
- Wheel speed sensor
- High speed CAN network
- Opportunities for *Connected Vehicle* apps



Data Utilization Via Connected Vehicle, e.g.

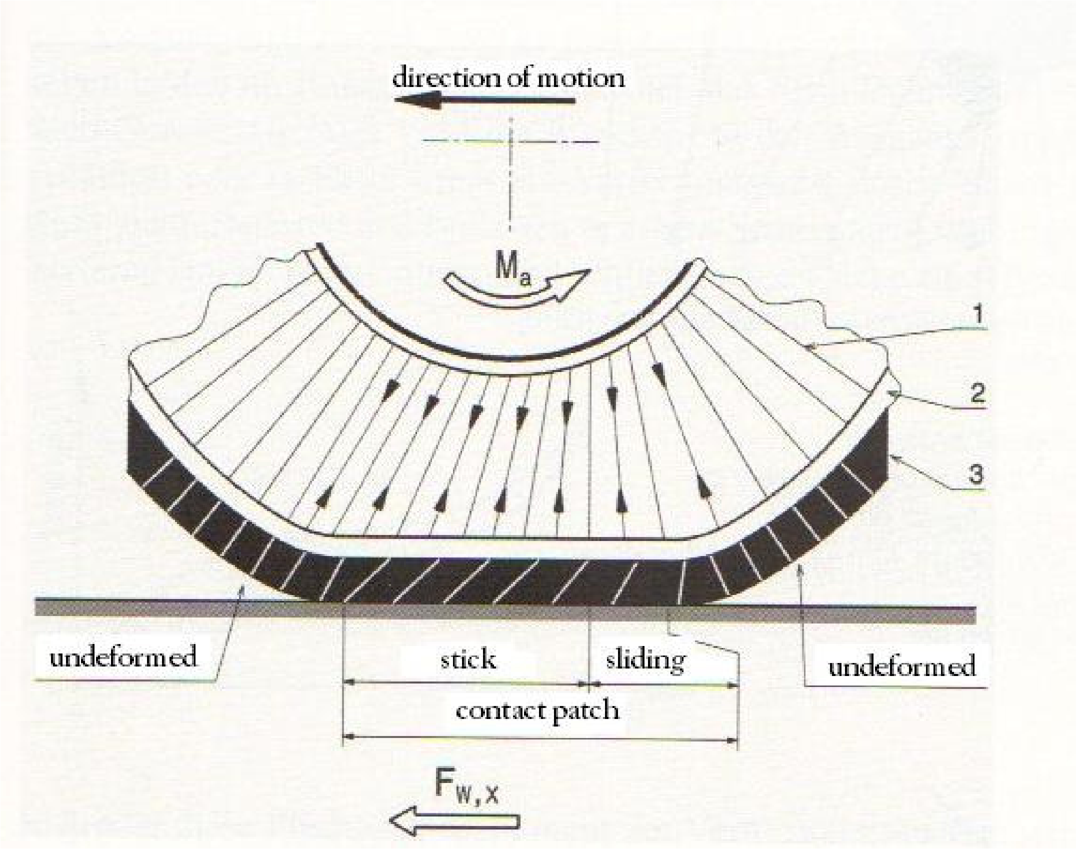
Adaptive/optimized winter maintenance operations



Vehicle Testing on the Virginia Smart Road

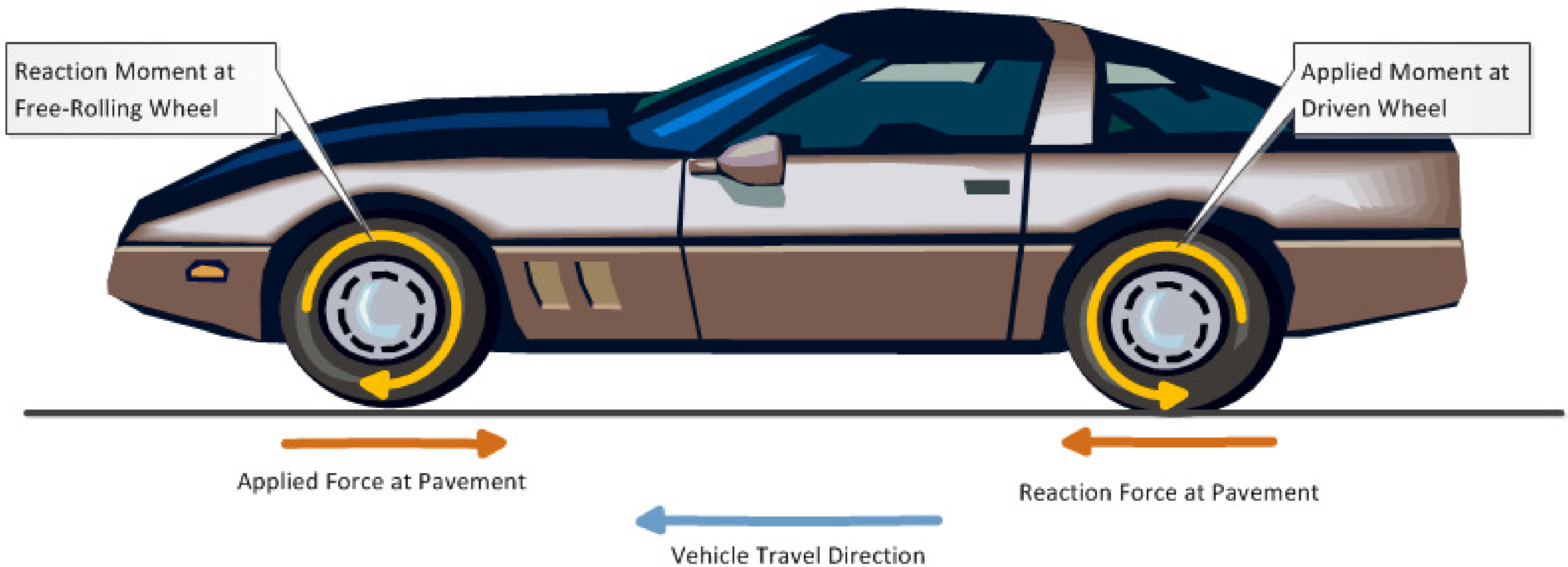
Smart Road Grade – Aerial View

Tire Contact Dynamics



- Observations on instrumented vehicles
- Micro-slip
- Macro-slip (used by on-board systems)

Force Diagram



- Rear wheel drive vehicle
- Constant speed
- Negligible road slope

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Proposed Integration in CV

- Use vehicle on-board sensors data from CAN bus to determine <u>relative</u> significant changes in road friction
- Report significant changes in road friction via *Connected Vehicle* network
- Issue safety advisories to approaching vehicles
- Optimize winter maintenance operations

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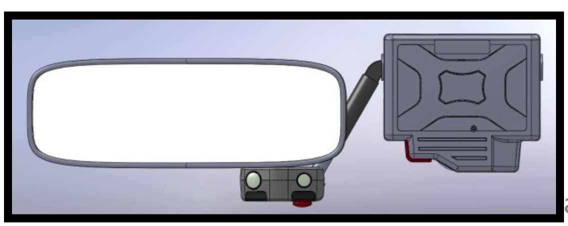
Experimental Methodology

- Operate instrumented vehicles on the Smart Road in various road surface and environmental conditions
- Monitor
  - Rotational rates of driven versus un-driven wheels
  - Distance traveled, weather variables, safety systems
- Determine rotational differential over time
- Predict relative friction values based on differential
- Compare to absolute friction measurements (e.g., GripTester)
  - At time of testing
  - Historical road friction data

Vehicle Data Acquisition

- Multiple Videos
  - Machine Vision Eyes Forward Monitor
  - Machine Vision Lane Tracker
- Accelerometer (linear acceleration, 3 axis)
- Gyroscope (angular velocity, 3 axis)
- GPS
  - Latitude, Longitude, Elevation, Time, Velocity
- Forward Radar
  - Tracking of 32 targets
- Cell Phone
  - ACN, health checks, location notification
  - Health checks, remote upgrades
- Illuminance sensor
- Passive alcohol sensor
- Incident push button



- Audio (only on incident push button)
- Turn signals
- Vehicle network data
  - Accelerator
  - Brake pedal activation
  - ABS
  - Gear position
  - Steering wheel angle
  - Speed
  - Seat Belt Information
  - Airbag deployment
  - Etc.

Virginia Smart Road

- 2.2 Miles controlled-access test track built to interstate standards
  - 2 paved lanes plus graded lanes
  - 3 bridges
- Pavement
  - 14 pavement sections (including open grade friction course)
  - In-pavement sensors (moisture, temp, strain, vibration, weigh-in-motion)
  - AASHTO-designated surface friction testing facility
- Control Room
  - Access control and oversight 24/7
  - Lighting and weather system control
  - Safety assurance and surveillance
- Weather
  - 75 weather-making towers (crowned and uncrowned pavement)
  - Snow up to 4”/hr.
  - Rain
  - Fog-like mist
  - Weather stations (2) plus NOAA nearby
- Lighting
  - Multiple luminaire heads including LED
  - Variable pole spacing to replicate 95% of national systems
  - Wireless mesh network control
- Communications
  - High bandwidth Fiber network
  - DSRC RSEs
  - Wi-Fi access points
  - Differential GPS base station

Artificial Precipitation on the Smart Road

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Experimental Data

- GPS time and position — Real-time differential correction will be used if it is found to have sufficient accuracy for concept validation. Post-collection processing of collected raw GPS satellite data may be performed if additional positional accuracy/precision is desired.
- Wheel rotation sensor pulse counts at all wheels from the CAN bus.
- Transmission output shaft sensor (vehicle speed).
- Status of ABS, ESC, and TSC from the CAN bus. Activation of these systems during tests would likely affect the outcome and need to be recognized as a confounding influence.
- Brake activation and applied torque at all wheels.
- Throttle, both applied and actual. On “drive-by-wire” vehicles input throttle and actual throttle may not match.
- Linear acceleration in the longitudinal and vertical axes for assessment of slope and/or vehicle acceleration. Preliminary tests should reveal whether additional gyroscopic data is required in the form of use of a full inertial measurement unit (IMU).
- Variables indicative of atmospheric conditions such as temperature, atmospheric pressure, windshield wiper and headlight activation, etc.

Connected Vehicle Demonstration

- Smart Road *Connected Vehicle* test-bed
- Continuous coverage by road-side equipment (RSE) for CV vehicle data
- Roadside weather stations
- Pavement temp sensors
- Transfer via optical fiber Ethernet backhaul to Control Center – data storage/management

Test Scenarios

Condition	Air Temperature	Pavement Temperature	Pavement Surface
A	35^{o} F +	35^{o} F +	Dry
B	35^{o} F +	35^{o} F +	Lightly wet
C	35^{o} F +	35^{o} F +	Very wet
D	28^{o} F -	28^{o} F -	Snow
E	35^{o} F +	28^{o} F -	Snow
F	28^{o} F -	28^{o} F -	Ice
G	35^{o} F +	28^{o} F -	Ice

Potential Challenges

- Wheel rotation data resolution
- Data acquisition from CAN bus
- Effects of
  - Road slope
  - Acceleration/deceleration
- Correlation with absolute measures of road friction
- Value of “relative” friction prediction

Potential Benefits

- Lives saved, fewer injuries
- Decreased property damage
- Better application of limited winter maintenance resources
- Increased mobility
- Decreased adverse environmental impact

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Questions? Comments?

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